Example 6c: MATLAB Post-Processing

This example problem demonstrates the use of MAC/GMC 4.0's capability to generate ASCII data files that can be used to generate local fringe plots using the MATLAB software package. MATLAB is a commonly-used commercial engineering and science oriented software package (see http://www.mathworks.com/) and must be independently licensed. Three MATLAB source files are shipped with the MAC/GMC 4.0 software. These are: `stress.m`, `strain.m`, and `epsp.m`. These files can be used within the MATLAB software to generate fringe plots from the MAC/GMC 4.0 MATLAB ASCII files. The user is free to customize these files in order to generate the plots desired.

The present example considers a 0.35 fiber volume fraction SiC/Ti-21S composite as both a cross-ply laminate and a unidirectional composite. The 7×7 circular fiber cross-section approximation RUC architecture is employed in both cases, and loading takes the form of a stress-free cool-down. The local residual fields for the unidirectional composite and the laminate are then compared using the MATLAB software fringe plots.

MAC/GMC Input File: `example_6c.mac`

```
MAC/GMC 4.0 Example 6c - MATLAB post-processing
*CONSTITUENTS
  NMATS=2
  M=1 CMOD=6 MATID=E
  M=2 CMOD=4 MATID=A
*LAMINATE
  NLY=3
  LY=1 THK=0.25 ANG=0.  MOD=2 ARCHID=6 VF=0.35 R=1. F=1 M=2
  LY=2 THK=0.50 ANG=90. MOD=2 ARCHID=6 VF=0.35 R=1. F=1 M=2
  LY=3 THK=0.25 ANG=0.  MOD=2 ARCHID=6 VF=0.35 R=1. F=1 M=2
#*RUC
#  MOD=2 ARCHID=6 VF=0.35 R=1. F=1 M=2
*THERM
  NPT=2 TI=0.,57600. TEMP=900.,23.
*SOLVER
  METHOD=1 NPT=2 TI=0.,57600. STP=40.
*PRINT
  NPL=6
*MATLAB
  N=1 TIMES=57600.
*XYPLOT
  FREQ=40
  LAMINATE=1
   NAME=example_6c  X=100 Y=1
  MACRO=0
#  MACRO=2
#   NAME=example_6c_1  X=100 Y=1
#   NAME=example_6c_2  X=100 Y=2
  MICRO=0
*END
```

Annotated Input Data

1) Flags: None

2) Constituent materials (**`*CONSTITUENTS`**) [KM_2]:

Number of materials:	2	(`NMATS=2`)
Materials:	SiC fiber	(`MATID=E`)
	Ti-21S	(`MATID=A`)
Constitutive models:	SiC fiber: linearly elastic	(`CMOD=6`)
	Ti-21S matrix: Isotropic GVIPS	(`CMOD=4`)

3) Analysis type:

Cross Ply Laminate (**`*LAMINATE`**) → Laminate Analysis [KM_3]:

Number of layers: 3 (`NLY=3`)

Layer	Analysis Model	Thickness	Fiber Angle	Architecture	Aspect Ratio	Volume fraction	Fiber material	Matrix material
(`LY=`)	(`MOD`)	(`THK`)	(`ANG`)	(`ARCHID`)	(`R`)	(`VF`)	(`F`)	(`M`)
1	GMC-2D	0.25	0°	7×7 circle rect. pack	1.	0.35	SiC	Ti-21S
2	GMC-2D	0.50	90°	7×7 circle rect. pack	1.	0.35	SiC	Ti-21S
3	GMC-2D	0.25	0°	7×7 circle rect. pack	1.	0.35	SiC	Ti-21S

Unidirectional Composite (**`*RUC`**) → Repeating Unit Cell Analysis [KM_3]:

Analysis model:	Doubly periodic GMC	(`MOD=2`)
RUC architecture:	7×7 circle approx., rect. pack	(`ARCHID=6`)
Fiber volume fraction:	0.35	(`VF=0.35`)
RUC aspect ratio:	1. (square pack)	(`R=1.`)
Material assignment:	SiC fiber	(`F=1`)
	Ti-21S matrix	(`M=2`)

☞ Note: In order to execute the code for the laminate and the unidirectional composite, the appropriate lines in the input file must be commented and uncommented.

4) Loading:

a) Mechanical (**`*MECH`**): None

b) Thermal (**`*THERM`**) [KM_4]:

Number of points:	2	(`NPT=2`)
Time points:	0., 57600. sec.	(`TI=0.,57600.`)
Temperature points:	900., 23. °C	(`TEMP=900.,23.`)

c) Time integration (**`*SOLVER`**) [KM_4]:

Time integration method:	Forward Euler	(`METHOD=1`)
Number of points:	2	(`NPT=2`)
Time points:	0., 57600. sec.	(`TI=0.,57600.`)
Time step sizes:	40. sec.	(`STP=40.`)

5) Damage and Failure: None

6) Output:

a) Output file print level (**`*PRINT`**) [KM_6]:

Print level:	6	(`NPL=6`)

b) MATLAB output (**`*MATLAB`**) [KM_6]:

Number of MATLAB output times:	1	(`N=1`)
MATLAB output times:	57600. sec.	(`TIMES=57600.`)

As shown above, the number of times desired for writing MATLAB output, and the times themselves, must be specified. MAC/GMC 4.0 generates five MATLAB output ASCII files for RUC analysis. In the case of laminate analysis, five separate files are output for each layer. These five files are:

`outfile``_x2.dat`	→ contains x_2 direction (β) grid coordinates
`outfile``_x3.dat`	→ contains x_3 direction (γ) grid coordinates
`outfile``_sig.dat`	→ contains local stresses
`outfile``_eps.dat`	→ contains local strains
`outfile``_epsp.dat`	→ contains local inelastic strains (plus material numbers)

where *`outfile`* is the name of the MAC/GMC 4.0 output file. In the case of laminate analysis, for layer numbers greater than 1, the layer number is appended to the file name root (e.g., *`outfile`*`_sig_2.dat`). In the case of RUC analysis, the local data for all specified `TIMES` is written to the same ASCII file, with the time value written prior to the data for each time. In the case of laminate analysis, the integration point number is also written on the same line as the time. The three MATLAB source files distributed with MAC/GMC 4.0 (`stress.m`, `strain.m`, and `epsp.m`) do not read these five ASCII files directly, rather they read the files: `x2.dat`, `x3.dat`, `sig.dat`, `eps.dat`, and `epsp.dat`. Thus, the ASCII files generated must be renamed. Further, the MATLAB source files only read the local data for a single time. Thus, the files `sig.dat`, `eps.dat`, and `epsp.dat` should contain only the local data for a single time (and integration point); the line on which the time (and integration point number) are written should not be present. For more information on the MAC/GMC 4.0 MATLAB output capabilities, see the MAC/GMC 4.0 Keywords Manual Section 6.

c) x-y plots (**`*XYPLOT`**) [KM_6]:

Frequency:	40	(`FREQ=40`)
Number of laminate plots:	1	(`LAMINATE=1`)
Laminate plot name:	example_6c	(`NAME=example_6c`)
Laminate plot x-y quantities:	temperature, ε_{xx}^{0}	(`X=100 Y=1`)
Number of macro plots:	2	(`MACRO=2`)
Macro plot names:	example_6c_1	(`NAME=example_6c_1`)
	example_6c_2	(`NAME=example_6c_2`)

Macro plot x-y quantities:	temperature, ε_{11}	`(X=100 Y=1)`
	temperature, ε_{22}	`(X=100 Y=2)`
Number of micro plots:	0	`(MICRO=0)`

☞ Note: In the case of laminate analysis, the lines of the input file associated with the macro c-y plots must be commented. Likewise, in the case of RUC analysis, the input file lines associated with the laminate level x-y plots must be commented.

7) End of file keyword: (**`*END`**)

Results

Figure 6.7 shows the predicted global strain response of the laminate and the unidirectional composite to the imposed thermal loading. The unidirectional composite exhibits significantly more strain in the transverse (x_2) direction compared to the longitudinal (x_1) direction. The response of the cross-ply laminate is identical in both the x and y directions, and the associated curve in Figure 6.7 falls in between the two curves that represent the unidirectional composite response.

In this example problem, MATLAB data was written at the end of the cool-down, at 23 °C. The stress and inelastic strain component fields, which represent residual fields in the composite and laminate due to the imposed stress-free thermal cool-down, are plotted in Figure 6.8 and Figure 6.9. It should be noted that the x_3-direction corresponds to the through-thickness (z) direction of the laminate (see Figure 1.2). From Figure 6.8 it is apparent that the stresses are noticeably higher in the cross-ply laminate as compared to the unidirectional composite. The presence of the stiff fibers along the x and y directions in the laminate act to restrain the thermal expansion of the composite, giving rise to the larger stresses. Figure 6.9 shows that, transverse to the fiber direction (x_2 and x_3 directions), the higher stresses present in the laminate give rise to higher tensile and compressive inelastic strain concentrations in certain subcells. In the unidirectional composite, the transverse inelastic strain fields present in the x_2 and x_3 directions are identical (but rotated 90°). In the fiber (x_1) direction, on the other hand, the restraint effect of the orthogonal layers of the laminate limits the matrix inelastic strain. Thus, the overall magnitude of ε_{11}^{in} is lower in the laminate compared to the unidirectional composite.

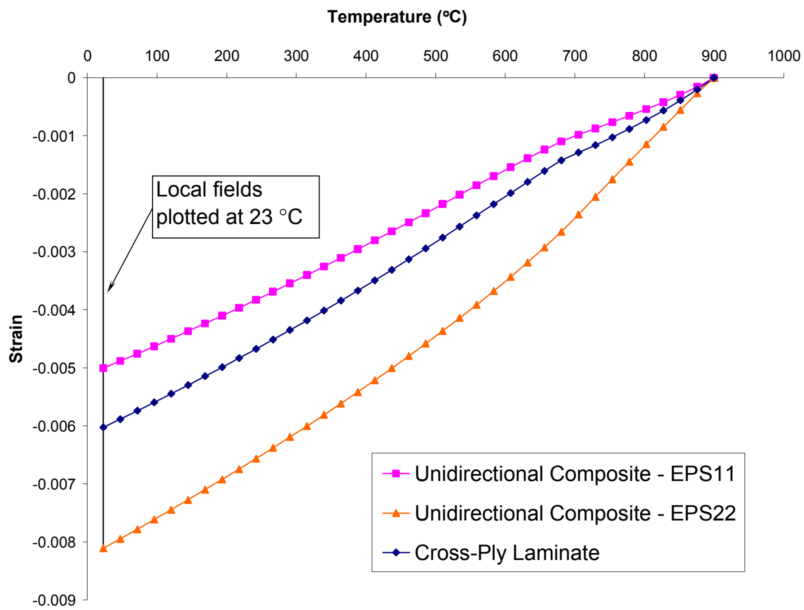

Figure 6.7 Example 6c: Predicted global response of unidirectional and cross-ply 35% SiC/Ti-21S during a stress-free cool-down.

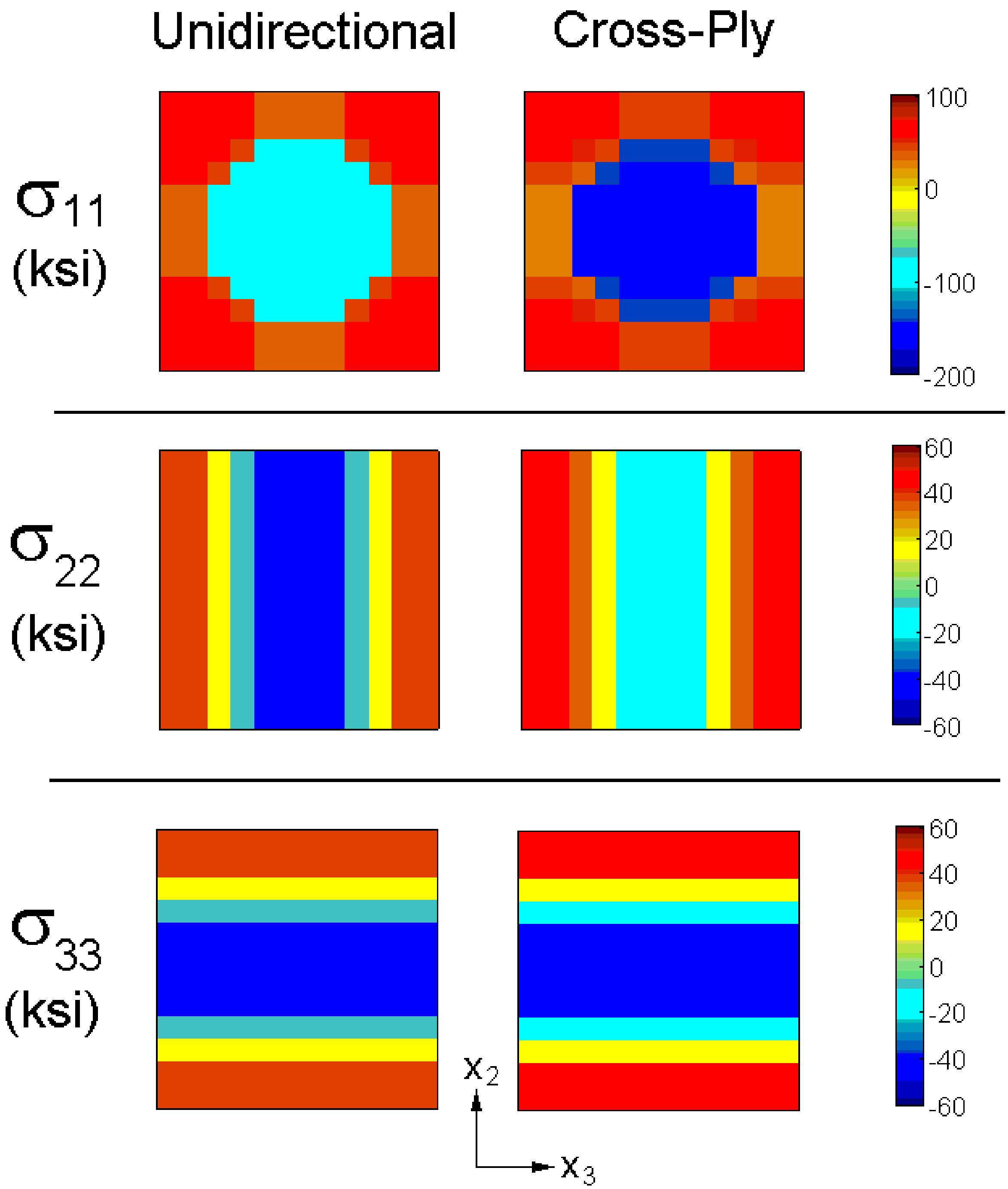

Figure 6.8 Predicted residual stress fields (plotted from MATLAB output data) for a unidirectional 35% SiC/Ti-21S composite and each ply within a cross-ply 35% SiC/Ti-21S laminate. Note that the fields in each ply of the laminate are identical in its local coordinate system.

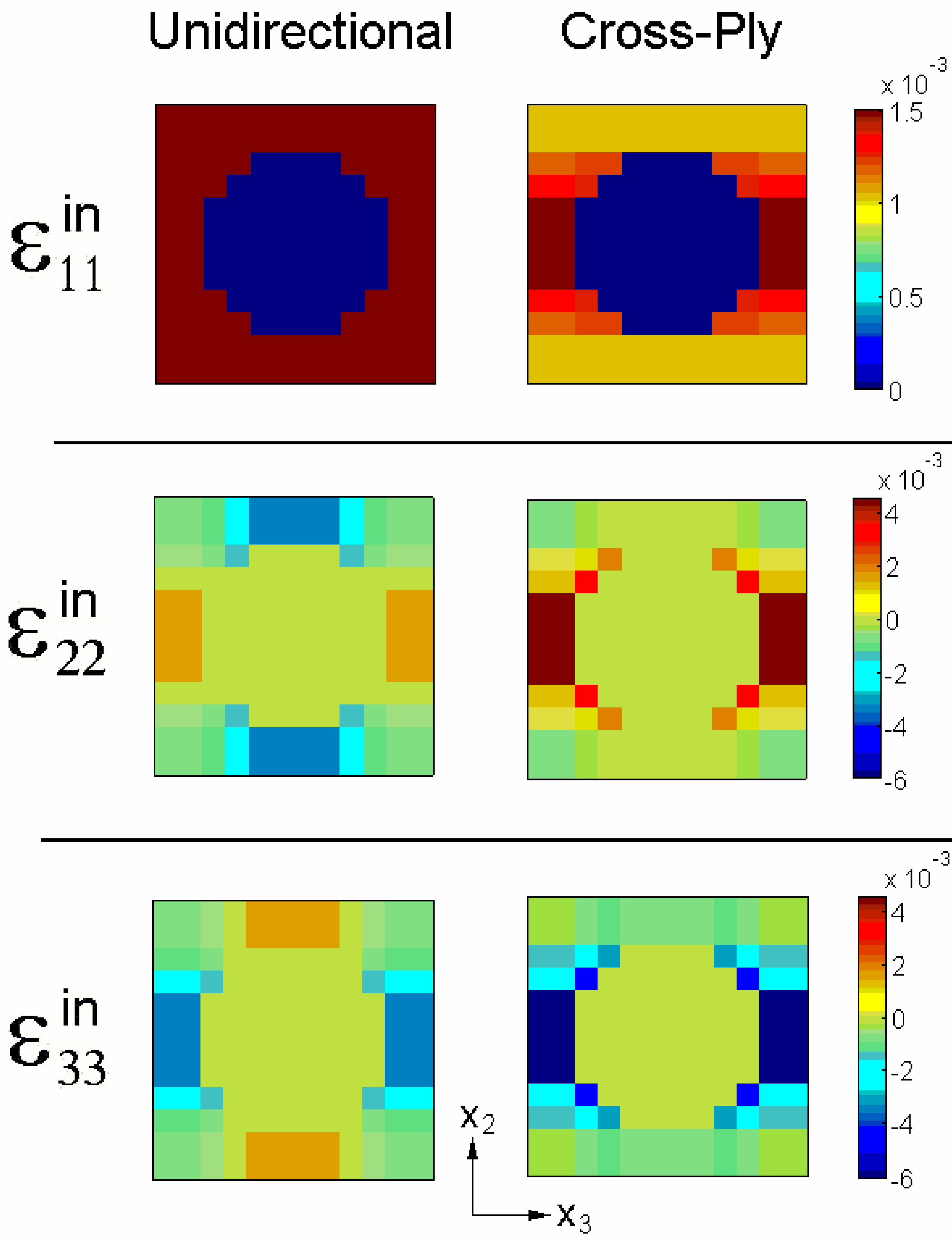

Figure 6.9 Predicted residual inelastic fields (plotted from MATLAB output data) for a unidirectional 35% SiC/Ti-21S composite and each ply within a cross-ply 35% SiC/Ti-21S laminate. Note that the fields in each ply of the laminate are identical in its local coordinate system.